Running headline: Lead in Big Sur Condors

LEAD CONCENTRATIONS IN THE BLOOD OF BIG SUR CALIFORNIA CONDORS

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ABSTRACT.- Lead poisoning in California Condors (*Gymnogyps californianus*) was first documented in the 1980s and continues to be a major threat to the recovery of the species. We collected 126 independent blood samples from 33 free-flying individuals in Big Sur, Monterey County, California, between 1998 and 2006. Thirty-three samples (26.2%) were above background (>20 μg/dl), four (3.2%) were clinically affected (60-99 μg/dl), and two (1.6%) were indicative of acute toxicity (≥100 μg/dl). Twenty-one individuals (64%) were exposed at least once and nine (27%) were exposed on two or more occasions. We found significant differences among calendar years, the number of years condors were in the wild, and month. Most notably, we found the months of September and October to be significantly higher than any other times of year, most likely due to condors feeding on hunter-killed deer during the fall deer-hunting season. One condor from the Big Sur population died due to lead poisoning in southern California and two additional birds were treated for acute poisoning to prevent mortality. We also found that blood-lead levels increased significantly after one year in the wild. The threat of lead exposure in Big Sur appears to be less severe than in Arizona and southern California. Nonetheless all condors in the wild are at risk of lead poisoning.

Key words: Big Sur, blood, California Condor, *Gymnogyps californianus*, lead poisoning.

Lead toxicity has long been recognized for its detrimental effects on the health of avian species. Mortality from lead poisoning has been extensively documented in both waterfowl and raptors (Locke and Thomas 1996, Kramer and Redig 1997, Fisher et al. 2006). During the late 1970s and early 1980s the endangered California Condor (*Gymnogyps californianus*) was significantly impacted by lead toxicity (Janssen et al. 1986, Weimeyer et al. 1988, Pattee et al. 1990). Data collected on the wild population from 1981-1986 confirmed three California Condor deaths caused by lead poisoning (Janssen et al. 1986). The precipitous historic condor population decline continued into the '80s, prompting the U.S. Fish and Wildlife Service (USFWS) to remove eggs and nestlings from the wild and to trap the remaining wild condors to initiate a captive breeding program (Snyder and Snyder 1989, 2000). In 1987 the last free-flying condor was captured from the wild bringing the captive population to 27 individuals. Successful captive breeding efforts doubled the population within a few years (Kuehler and Witman 1988) and in 1992 the first captive-born condors were released into the wild in southern California (Snyder and Snyder 2000). By January 2006, 128 condors were free-flying in the wild following releases in California and Arizona, USA, and Baja California, Mexico.

The recovery goal set for California Condors is to establish at least two self-sustaining wild populations of 150 condors (Kiff et al. 1996). Ventana Wildlife Society, in cooperation with the USFWS, began releasing condors in Big Sur, Monterey County, California, in 1997. In 2003, a cooperative release effort between Ventana Wildlife Society and the National Park Service began at Pinnacles National Monument, San Benito County, approximately 45 km east of the Big Sur release site. By January 2006 the condor population in California stood at 57 individuals, including 37 in central California (28 in Big Sur and 13 at Pinnacles National Monument) and 20 in southern California.

California Condors forage exclusively on carrion (Koford 1953) and are known to ingest lead residues and fragments from carcasses shot with ammunition (Janssen et al. 1986, Weimeyer et al. 1986, Hunt et al. 2006). Although the timing of deer hunting seasons vary between release areas, condors in both Arizona and southern California have significantly higher blood-lead levels during those months (see Hall et al., Hunt et al. this volume). Lead poisoning accounted for six confirmed and two suspected deaths in Arizona from 1996 to 2005 and is the leading known cause of mortality in that population (Woods et al. this volume). In southern California a total of three condors have died from lead poisoning between 1992 and 2005, presenting a major limiting factor in recovery efforts in that region (see Hall et al. this volume). Given the extent of lead exposure in the recent historic and reintroduced populations, blood sampling for this toxin was initiated for Big Sur condors in 1998. The purpose of this study is to determine whether wild condors in Big Sur have experienced any lead exposure events since releases began in 1997, and if so, to analyze exposure patterns.

METHODS

Study site.-The condor release site used for this project was located in Big Sur, Monterey County, California, on the western slope of the Santa Lucia Mountains, 1 km east of the Pacific coastline, at an elevation of 818 m. The release pen (Fig 1) consisted of an observation blind and a large netted aviary, 7.8 m wide x 14.1 m long x 9.4 m high.

Captive breeding facilities in southern California (Los Angeles Zoo and San Diego Wild Animal Park) annually transferred condors at 3-9 months of age to the release site from 1997 to 2006. After arriving at the field site, condors were held in the release pen for a minimum acclimation period of 90 days. Young condors spent a majority of their acclimation period in the aviary portion of the release pen. The aviary contained natural perching, pool, perch scales; and a mock power-pole, which was utilized for behavioral aversion training to counter potential landing on utility following release (Snyder and Snyder 2000). An adult condor was placed temporarily in the aviary as a mentor to young release candidates (Clark et al. this volume). Inside the aviary condors were primarily fed small to large-sized carcasses consisting of stillborn calves (*Bos taurus*), domestic rabbits (*Oryclolagus cuniculus*), and rats (*Rattus norvegicus*).

The first supplemental feeding station for condors post-release was established in a large grassy area adjacent to the release pen. In the first two years of releases, five additional supplemental feeding stations were established north of the release site in suitable open grassland habitat at 800-1200 m elevation. Food was randomly moved between the stations to promote food searching and to provide a non-lead food source for the birds. The principal foods provided at feeding stations were domestic rat, rabbit, calves; secondary food items included black-tailed deer (*Odocoileus hemionus californicus*), feral pig (*Sus scrofa*), tule elk (*Cervus nannodes*), and domestic sheep (*Ovis aries*). We observed condors feeding at each station, as well as at non-proffered food sites (wild food), to record individual use and establish feeding histories.

Prior to release condors were fitted with patagially mounted VHF transmitters (Biotrack Ltd, Wareham, Dorset, UK), or PTT GPS satellite transmitters (Microwave Telemetry

Inc.), to track post-release movements and to determine mortality causes. Individually unique wing-tags showing each condor's studbook number (see Mace 2006) were attached in conjunction with transmitters for visual verification in the field.

Trapping and lead sampling.-Recapturing condors for lead testing and routine transmitter replacements began in 1998 using a "walk-in" trap. We attempted to capture each bird at least once per year. The walk-in trap, 5 m^2 by 1.9 m in height, was made of chain-link fence with a netted roof. The trap was baited prior to a capture event to encourage condors to enter in and out. The trap door was closed using a rope pulley operated from an observation blind. A second trapping method was instituted in 1999 by adding a double-door trap system (Fig 1) to the release pen's aviary. The double-door trap, 2 m^3, enabled biologists to capture individuals without handling and to hold them until processing. Doors were opened and closed using cable pulleys operated from inside the release pen's observation blind. The same baiting strategy was used in both types of walk-in trap.

In both trapping scenarios the handling and sampling of condors were the same. Condors were individually captured using a hand net and each bird was restrained by three people. An additional person collected an intravenous 3.0 ml blood sample from the medial-tarsal vein using a 21-ga. needle and heparinized storage tubes. On-site lead analysis was conducted on blood using a portable lead analyzer (Lead Care Blood Lead Testing System, ESA Inc, Chelmsford, MA, USA) capable of measuring lead levels from 0 to 65 mg/dl. A 1.5 ml vial of blood was stored on ice and subsequently sent for laboratory analysis (Louisiana Animal Disease Diagnostic Laboratory, Baton Rouge, LA). In most, but not all cases, a pre-release blood sample was collected. Pre-release blood samples collected at captive breeding facilities were submitted to the California Animal Health and Food Safety Lab system in Davis, California, IDEXX Veterinary Services or Antech Laboratories. We grouped the blood-lead results using the convention of Redig (1984) converted to μg/dl: <20 = background; 20 to 59 = exposed; 60 to 99 = clinically affected; ≥ 100 = acute toxicity.

Statistical analyses.—Fry and Maurer (2003) calculated the depuration rate of lead in condor blood to be 13.3 days ± 6.5 days. In our analyses, we considered blood samples from the same individual as independent if they occurred more than 20 days apart. We tested for normality using the Kolmogorov-Smirnov One Sample Test and found that the data were not normally distributed, and therefore all tests used were nonparametric. We compared blood-lead results by calendar year, month, season, sex, and the number of years a condor was in the wild using Kruskal-Wallis One-Way Analysis of Variance (ANOVAs), and Mann-Whitney U-tests where appropriate. In addition, we used linear regression analysis (after natural log data transformations) to determine the relationship between blood-lead levels and years in the wild and calendar year. We used Wilcoxon Signed-Ranked tests to compare pre- and post-release samples within and after one year in the wild. Given the use of several different labs, we determined the least common denominator among all the lab's lower detection limit (3 μg/dl) and adjusted upwards all blood-lead values that were reported below this value so as to avoid artificial results. Only blood samples collected prior to each individual's first documented visit to southern California were used to approximate lead exposure in Big Sur. We compared the blood-lead values between the portable lead analyzer and the laboratory result using a Wilcoxon

Signed-Rank test as well as a linear regression analysis. However, only blood lead lab values were used in our analyses.

RESULTS

Lead exposure.-A total of 126 independent blood-lead samples from 33 free-flying condors was collected between May 1998 and June 2006, during which time Ventana Wildlife Society biologists released 42 condors to the wild in Big Sur. Of the 126 lab samples, 69 were also measured using the field tester. Although there was a strong relationship between field and lead values ($R^2 = 0.744$, $P < 0.001$), lab values were on average 21% higher. Thus, only the lab results ($n = 126$) were used for the remaining analyses. Of the 126 post-release blood-lead samples, 33 (26.2%) were indicative of exposure or clinically affected or acute poisoning events and 93 (73.8%) were background. Total post-release blood-lead concentrations ranged from as low as 2.0 µg/dl to as high as 170.0 µg/dl. Twenty-one (64%) of free-flying individuals sampled were exposed at least once and nine (27%) were exposed on two or more occasions. The ratio of birds sampled relative to those in the wild varied from 38% (2004) to 100% (2000) while the percentage of birds exposed ranged from 0% to 50% (Fig. 2). We found no difference in blood-lead values between the sexes ($U = 1752.0$, $P = 0.393$).

Yearly variation.-We found significant variation in blood-lead levels among calendar years ($F = 22.01$, $P = 0.005$, $n = 126$). Yearly mean blood-lead levels ranged from 3.3 µg/dl to 29.7 µg/dl (Table 1), with 2005 being the worst year. Blood-lead levels also differed depending on the number of years a condor was in the wild ($F = 31.15$, $P <$

0.001), where levels were generally higher after the first year in the wild (Table 2). Mean lead values were highest during condors' sixth and eighth years in the wild (Table 2). We also found a significant difference among months of the year ($F = 35.661$, $P < 0.001$). Concerned that we were obtaining skewed results due to the inclusion of the two highest blood-lead values (100 and 170 μg/dl), we excluded these data and ran the same tests; however variation among calendar years ($n = 124$, $F = 20.70$, $P = 0.008$), years in the wild ($F = 29.57$, $P = 0.001$), and month ($F = 40.33$, $P < 0.001$) remained significant. We compared the variation among six, two-month periods (Table 3) and found a significant difference in blood lead levels ($F = 29.35$, $P < 0.001$), with the Sep-Oct period showing the highest levels (mean = 30.4 ± SD 19.5, $n = 31$).

Movements and post-release exposure.- Of the 33 birds sampled, 21 condors (64%) released in Big Sur made at least one visit to southern California whereas 8 (24%) had not yet made the trip by June 2006; 3 (9%) were removed from the population; and 1 (3%) died prior to making a first trip. One bird remained in the Big Sur area for nearly four years and had yet to visit southern California. Of those that did visit southern California they did so for the first time an average of some two years after release (mean = 1.9 ± SD 0.55). Of the 33 individuals, 25 were sampled prior to their initial release. Of those that were sampled before their initial release, 16 condors were also sampled before visiting southern California and within one year in the wild and only 13 (many of the same individuals) were sampled after one year in the wild. Twenty nine of the 126 post-release samples were used after meeting both criteria for the purposes of these tests. We found no difference between pre-release blood-lead samples and those collected within one year of release in Big Sur ($Z = -0.911$, $P = 0.362$, $n = 16$). However, blood-lead samples of free-flying Big Sur condors after one year in the wild were significantly higher than pre-release values ($Z = 2.090$, $P = 0.037$, $n = 13$).

We documented Big Sur condors feeding routinely at the supplemental feeding stations as well as at sites where non-proffered food items were found by condors. Between March 1999 and June 2006, we documented condors feeding on 26 non-proffered food items in Big Sur, including 20 (76.9 %) California sea lions (*Zalophus californianus californianus*), 3 (11.5%) black-tailed deer, and single (3.8%) tule elk, gray whale (*Eschrichitus robustus*), and domestic cattle.

Discussion

Our study found that 26% (33 of 126) of the blood samples for California Condors released to date in Big Sur showed exposure to lead above background levels between 1998 and 2006. Also, in six cases, condors were clinically or acutely affected. Blood-lead levels in condors in September and October were significantly higher than in all the remaining months combined. Also, blood-lead samples of free-flying Big Sur condors after one year in the wild were significantly higher than their pre-release values, indicating that Big Sur condors are experiencing lead exposure similarly to all of the other populations of recovered condors (Parish et al. this volume, Hall et al. this volume).

Although the overall threat of lead exposure to condors in Big Sur (26% above background) was less than that documented in southern California (44%; Hall et al. this volume) and Arizona (40%; Parish et al. this volume), it is still very significant indicating that ingestion of lead by condors is occurring at an alarming rate. In Big Sur, no deaths of condors specifically due to lead ingestion occurred during the present study. However, one Big Sur condor died in June 2003 of severe visceral gout complicated by lead poisoning in southern California. In addition, 2 acute lead poisoning events were recorded in Big Sur condors, whereas there were 6 such acute exposures in southern California (Hall et al. this volume) and 25 in northern Arizona (Parish et al. this volume). However, it should be noted that southern California and northern Arizona sampled more birds (214 and 437 samples from 44 and 50 birds respectively) up to the end of 2005 (Hall et al., Parish et al. this volume).

The majority of hunter-shot deer occur in August and September within the coast ranges where Big Sur is located (Fry and Maurer 2003), which may explain why blood-lead levels in condors in September and October were significantly higher than in all the remaining months combined. As has been shown in other, recent condor studies (e.g., Hall et al., Hunt et al., Parish et al. this volume), fall lead exposure events seem to be tied to the deer hunting season, since whole deer carcasses or lead-contaminated gut piles left in the field in mid- to late August are commonly eaten by scavengers such as condors. Lead exposure due to ingestion of bullet fragments or lead shot in carrion has also been widely reported for scavenging raptors where poisoning events often closely track the hunting seasons for food sources of these species (see review in Fisher et al. 2006).

The most likely explanation for why blood-lead levels in Big Sur are less severe than those in the other reintroduced populations, is the unique marine influence and a strong preference among Big Sur condors for sea lion carrion, which accounted for 77% of their non-proffered diet during our study. In roughly the same time period, 78 cases of deer foraging were documented in Arizona (Hunt et al. this volume) whereas we only found three such cases. Nevertheless, Big Sur condors overlap in range with southern California birds and all individuals in California are at risk of exposure to lead poisoning, some of which can be fatal.

Replacement of lead ammunition with non-toxic ammunition must be a top priority for the California Condor Recovery Program. Arizona Department of Game and Fish implemented a non-lead coupon program for deer hunters in 2005, during which they provided hunters the opportunity to receive non-lead ammunition free of charge. Of those hunters that used non-lead ammunition, 93% stated that it performed as good or better than lead, and 72% would recommend its use to other hunters (Sullivan et al. this volume). While a prohibition on the use of lead ammunition in California would be the most direct way to address the issue, we are concerned that enforcement would prove to be challenging due to difficulties differentiating between lead and non-lead bullets and a current lack of law enforcement personnel in the field. Given the positive results of the Arizona coupon program, we recommend that a similar effort -- coupled with a prohibition -- be implemented within the range of the condor in California, particularly if voluntary efforts alone do not solve the problem.

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Table 1. Yearly variation in blood-lead levels (in ug/dl) of California Condors at Big Sur, California, 1998-2006.

Year	n	Mean blood-level	Min	Max	SD
1998	4	3.3	2	6	1.9
1999	5	8.8	3	17	6.7
2000	14	20.1	2	62	20.1
2001	18	10.1	2	37	8.5
2002	20	21.0	5	80	21.0
2003	19	22.0	2	100	24.3
2004	10	11.7	2	29	8.6
2005	22	29.7	3	170	36.3
2006[a]	14	7.9	2	19	5.1

[a] Data analysis includes results up to June 2006.

Table 2. Variation in blood-lead levels (in ug/dl) of California Condors at Big Sur, California, by the number of years condors were in the wild.

Year(s) in wild	n	Mean blood-lead levels	Min	Max	SD
1	18	5.6	2	46	10.5
2	36	14.4	2	38	11.5
3	18	26.1	3	80	22.1
4	14	21.3	2	100	24.4
5	19	17.2	5	61	14.0
6	11	29.1	4	170	48.4
7	4	16.8	4	42	17.3
8	4	29.8	8	76	31.8
9	2	9.5	5	14	6.4

Table 3. Bi-monthly variation in blood-lead levels (in ug/dl) of California Condors in Big Sur, California, 1998-2006.

Months	n	Mean blood-lead levels	Min	Max	SD
Jan-Feb	3	8.0	4	15	6.1
Mar-Apr	11	9.9	3	22	5.8
May-Jun	38	14.7	2	100	19.4
Jul-Aug	23	9.4	2	38	8.4
Sep-Oct	31	30.4	3	80	19.5
Nov-Dec	20	19.5	2	170	36.2

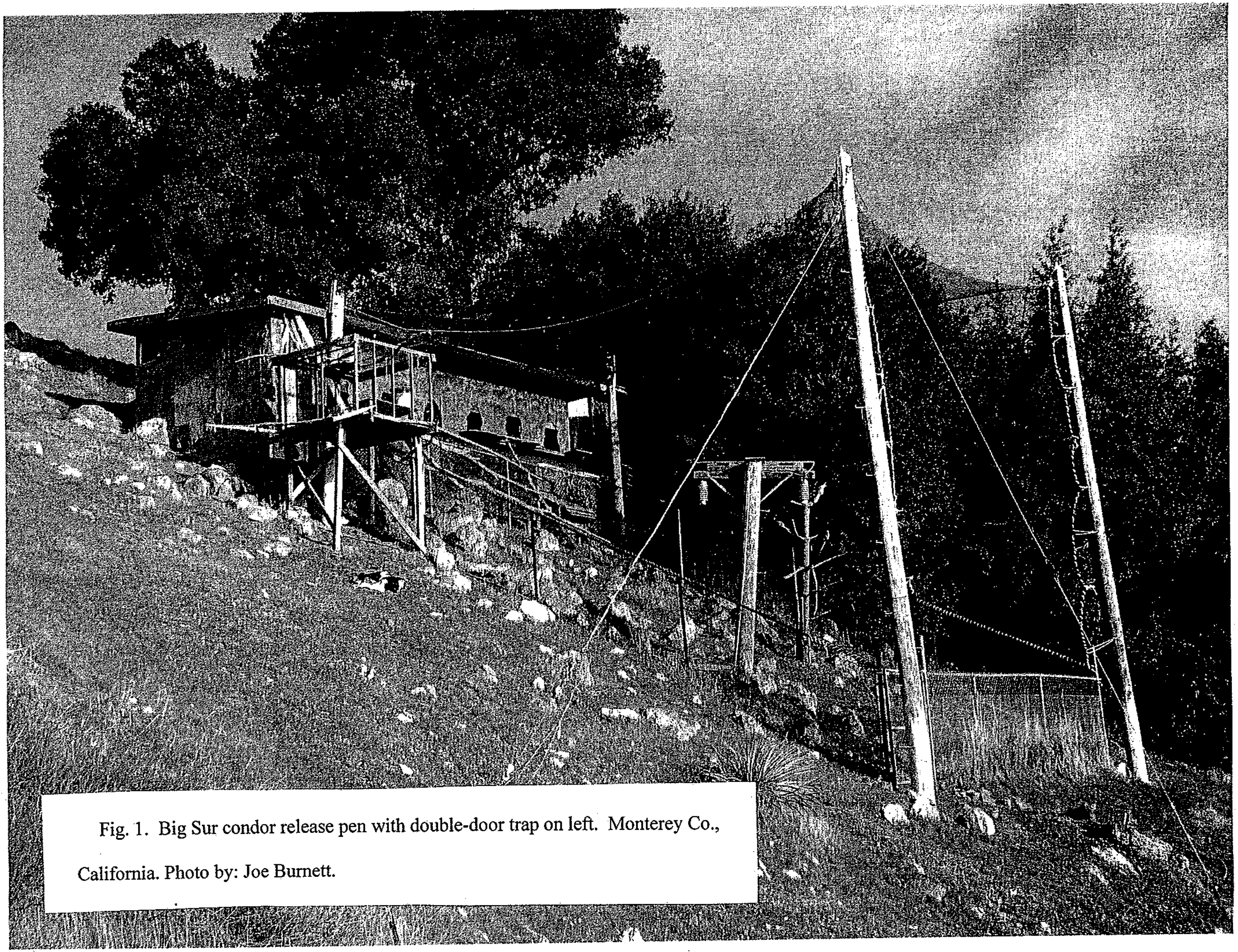

Fig. 1. Big Sur condor release pen with double-door trap on left. Monterey Co., California. Photo by: Joe Burnett.

Fig. 2. Number of condors in the wild, blood-lead tested and exposed by calendar year. Five condors in 1998 were released on 12 December 1997. ** In 2006, results were based on samples through June and not the full calendar year.